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Modeling and Control of Negative output Triple-Lift Luo Converter Using Fuzzy Logic Controller

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***Abstract*— The voltage lift technique is a popular method widely applied in electronic circuit design. Since the effect of parasitic elements limits the output voltage and power transfer efficiency of DC-DC converters, the voltage lift technique improve circuit characteristics. This technique has been successfully applied for DC-DC converters resulting Luo converters. Negative output Triple-Lift Luo converters are another series of new DC-DC step-up (boost) converters, which were developed from elementary Luo converter using the voltage lift technique. Triple lift LUO circuit is derived from negative output elementary Luo converter by adding the lift circuit three times. These converters perform positive to negative DC-DC voltage-increasing conversion with high power density, high efficiency and cheap topology in simple structure. Since the power electronic converters become very complex, soft computing techniques are proper choice for controlling these systems. The classical control methods employed to design the controllers for Luo converters depend on the operating point so that it is very difficult to select control parameters because of the presence of parasitic elements, time varying loads and variable supply voltages. Conventional controllers require a good knowledge of the system and accurate tuning in order to obtain the desired performances. A Fuzzy Logic Controller (FLC) which is one of the soft computing technique has been developed for the control of Triple-Lift converter to achieve good dynamic performances i.e. minimum value of rise time, settling time and peak overshoot in the presence of input voltage variations and load changes and invariant dynamic performance in the presence of varying operating conditions. The proposed technique is evaluated on a Luo converter under different operating conditions by using MATLAB - SIMULINK software. The results are presented and analysed.**

***Index Terms*— DC-DC Converters, Fuzzy Logic Controller, Negative output Triple-Lift Luo Converter, Membership function.**

I. INTRODUCTION

DC-DC step-up converters are widely used in computer hardware and industrial applications such as computer peripheral power supplies, car auxiliary power supplies, servo-motor drives, and medical equipments. For DC/DC converters with constant output voltage, it is always desirable that the output voltage remains unchanged in both steady state and transient operations whenever the supply voltage and/or load current are disturbed. This condition is known as zero-voltage regulation and it means that the output voltage is independent of the supply voltage and the load current. The DC-DC converters are generally divided into two groups: hard switching converters and soft-switching converters. In hard-switching converters, the power switches cut off the load current within the turn-on and turnoff times under the hard switching conditions. The output voltage is controlled by adjusting the on time of the power switch, which in turn adjusts the width of a voltage pulse at the output. This is known as PWM control. Because of the effect of parasitic elements, the output voltage and power transfer efficiency of all DC-DC converters is restricted. The elementary Luo circuit which can perform step-down and step-up DC-DC conversion. Other negative output Luo converters are derived from this elementary circuit; they are the self-lift circuit, re-lift circuit and multiple-lift circuits (e.g. triple-lift and quadruple-lift circuits).The commonly used control methods for dc-dc converters are pulse width modulated (PWM) voltage mode control, PWM current mode control and PID controller. These conventional controllers are unable to perform satisfactorily under large parameter or load variation. Fuzzy logic control uses linguistic variables in the form of IF THEN rules to capture the nonlinear system dynamics and achieving voltage regulation. Since, the fuzzy logic controller work very well for nonlinear, time variant and complex systems, this research work presents a control of a negative output Triple- Lift Luo Converter using FLC for controlling the DC output voltage. Simulations are made in MATLAB. Test for load regulation and line regulation are carried out to evaluate the performances of the controller.

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II. ANALYSIS OF NEGATIVE OUTPUT TRIPLE –LIFT LUO CONVERTER

The elementary circuit can perform step-down and step-up DC-DC conversion. The other negative output Luo converters are derived from this elementary circuit; they are the self-lift circuit, re-lift circuit and multiple lift circuits (e.g. triple-lift and quadruple-lift circuits). The negative output triple-lift circuit is shown in Fig.1. Switch S is a P-channel power MOSFET device (PMOS). It is driven by a pulse width modulated (PWM) switching signal with repeating frequency f and conduction duty k. The switch repeating period is T = 1/f so that the switch-on period is kT and the switch-off period is (1 - k)T. The load is usually resistive, i.e., $R = V_o/Z_o$; the normalised load is Z_n=R/fL . Each converter consists of a pump circuit S-L-D-(C) and a lI-type filter C-L_o-C_o, as well as a lift circuit. The pump inductor L absorbs energy from the source during switch-on, and transfers the stored energy to capacitor C during switch-off. The energy on capacitor C is then delivered to the load during switch-on. Therefore, if the voltage V, is high, the output voltage V_o is correspondingly high. When the switch S is turned off, the current i_o flows through the freewheeling diode D. This current descends in a whole switching-off period (1 - k)T. If the current i_o does not

reach zero before switch S is turned on again, this working state is defined as a continuous mode. If the current i_o reaches zero before switch S is turned on again, this working state is defined as a discontinuous mode.

Negative output Triple-Lift Circuit consists of one static switch S, four inductors L, L_1, L2 and Lo, five capacitors C, C_l, C_2, C_3 and C_O, and diodes. The circuit C_1-D_1-L_l-C_2-D_2-D_{11}-L_2-C_3-D_3-D_{12} is the lift circuit. Capacitors C_1, C_2 and C_3perform characteristics to lift the capacitor voltage V_c by three times the source voltage V_I, L_1 and L_2 perform the function of ladder joints to link the three capacitors C_1,C_2 and C_3 and raise the capacitor voltage V_c. The currents $i_{C1}(t)$, $i_{c2}(t)$ and $i_{C3}(t)$ are exponential functions. They have large values at the moment of power-on, but they are small, because $V_{C1} = V_{C2} = Vc_3 = V_I$ in the steady state.

The output voltage and current are

$$V_0 = \frac{3}{1-k} V_I \quad (1)$$

$$I_0 = \frac{3}{1-k} I_I \quad (2)$$

The voltage transfer gain in continuous mode is

$$M_T = {}^{V_0}/_{V_I} = \frac{3}{1-k} \quad (3)$$

Other average voltages:

$$V_c = V_0 \,;\, V_{C1} = V_{C2} = V_{C3} = V_I \quad (4)$$

Other average currents:

$I_{L0} = I_0$;

$$I_L = I_{L1} = I_{L2} = \frac{1}{1-k} I_0 \quad (5)$$

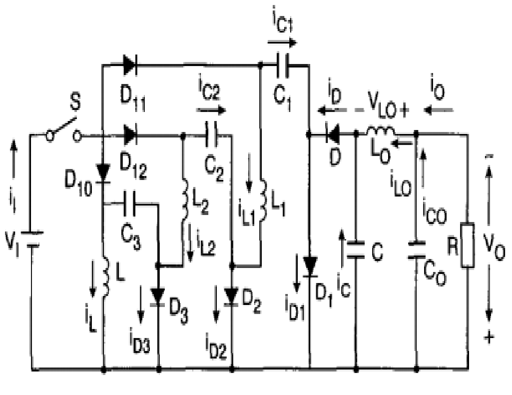

Fig.1 Negative Output Triple-Lift Luo converter

Table 1. Circuit parameters of Triple –Lift LUO converter

Parameters	Symbol	Values
Input voltage	V_{in}	10 V
Output voltage	V_o	-60V
Inductors	L-L_1-L_2-L_0	100µH
Capacitors	C_0-C1-C2-C3-C	5µf
Load resistance	R	10Ω
Switching frequency	f_s	50KHZ
Duty ratio	d	0.5

III. FUZZY LOGIC CONTROLLER

The block diagram of the fuzzy logic control scheme for the Negative output Triple-Lift Luo converter is shown in Fig.2.The output voltage of the Luo converter is compared with the reference voltage. After comparison, the error (e) and the change in error (ce) are calculated and are given as inputs to the fuzzy controller. In this work, the error is normalized to a per-unit value with respect to the reference voltage, which helps in using the fuzzy controller for any reference voltage. The fuzzy controller will attempt to reduce the error to zero by changing the duty cycle of switching signal. The fuzzy controller is divided into five modules: fuzzifier, data base, rule base, decision maker and defuzzifier. Various steps in the design of FLC for chosen Luo converter are stated below:

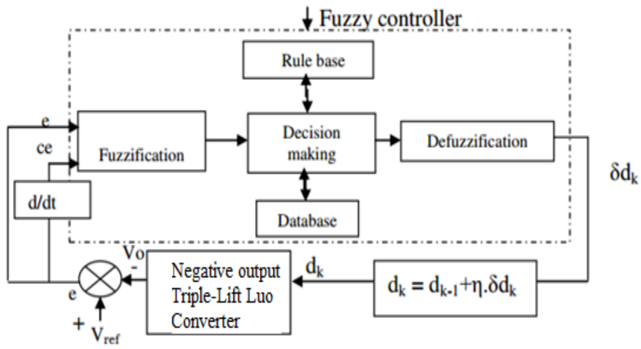

Fig.2 Block Diagram of fuzzy logic control for a Negative output Triple- Lift Luo converter

A. Fuzzification

FLC uses linguistic variables instead of numerical variables. The process of converting a numerical variable (real number or crisp variables) into a linguistic variable (fuzzy number) is called fuzzification. In the present work, the error and change in error of voltage are fuzzified. Seven linguistic fuzzy sets with triangular membership function are as shown in Fig. 3. The seven fuzzy variables for 'error', 'change in error' and change in the duty cycle are Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Big (PB), Positive Medium (PM) and Positive Small (PS).

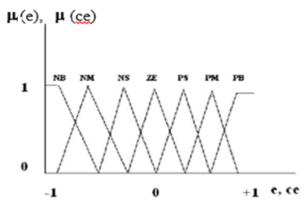

Fig. 3 Membership functions for e,ce

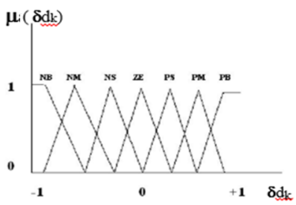

Fig. 4 Membership functions for δd_k

B .Rule Table and Inference Engine

The derivation of the fuzzy control rules is heuristic in nature and based on the following criteria:

1. When the output of the converter is far from the set point, the change of duty cycle must be large so as to bring the output to the set point quickly.

2. When the output of the converter is approaching the set point, a small change of duty cycle is necessary.

3. When the output of the converter is near the set point and is approaching it rapidly, the duty cycle must be kept constant so as to prevent overshoot.

4. When the set point is reached and the output is still changing, the duty cycle must be changed a little bit to prevent the output from moving away.

5.When the set point is reached and the output is steady, the duty cycle remains unchanged and when the output is above the set point, the sign of the change of duty cycle must be negative and vice versa.

According to these criteria, a rule table is derived and is shown in Table 2.From the rule table, the rules are manipulated as follows: If error is NB, and change in error is NB, then output is NB.

Table 2 Rule base for FLC

ce \ c	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

C.. Defuzzification

The FLC produces the required output in a linguistic variable (fuzzy number). According to real-world requirements, the linguistic variables have to be transformed to crisp output. Center of gravity method is used for defuzzification in this work. The defuzzified output is the change in duty cycle.

$$\delta d_k = \frac{\sum_{i=1}^{4} w_i m_i}{\sum_{i=1}^{4} w_i} \qquad (6)$$

Where W_i - Weighting factor, m_i- Centroid.

IV. SIMULATION RESULTS AND DISCUSSION

Fig.5 shows the output voltage for the Negative output Triple –Lift Luo converter subject to the step change of the line voltage. When the input voltage is increased suddenly from 10 V to 12.5 V, the duty cycle has to compensate by reducing its value to keep the output voltage constant. It is observed that the settling time is 5ms and peak overshoot is 7.5% and when the input voltage is changed from 10V-7.5V the settling time is 7ms and the peak overshoot 6.67% under line disturbances.

The fuzzy logic controller considered for a Triple- Lift Luo converter under load regulation is shown in Fig.6. When the load resistance increases suddenly from 10 Ω to 12 Ω at 0.035 sec the duty cycle increases resulting in increasing the output voltage before it stabilizes again. The settling time and the % peak overshoot are 6 ms and 8.3. On the other hand, when the load suddenly changes from 10 Ω to 8 Ω at time 0.07 sec, the original duty cycle decreases resulting in decreasing the converter output voltage before it stabilizes again. The settling time and the % peak overshoot are 3ms and 5.83.When the output voltage is lower than its reference value, the fuzzy rules always try to add positive change of the duty cycle to bring the output voltage as close as possible to its reference value. When the output voltage is higher than its reference value, the fuzzy rules add negative change to the duty cycle to bring the output voltage back to its reference value.

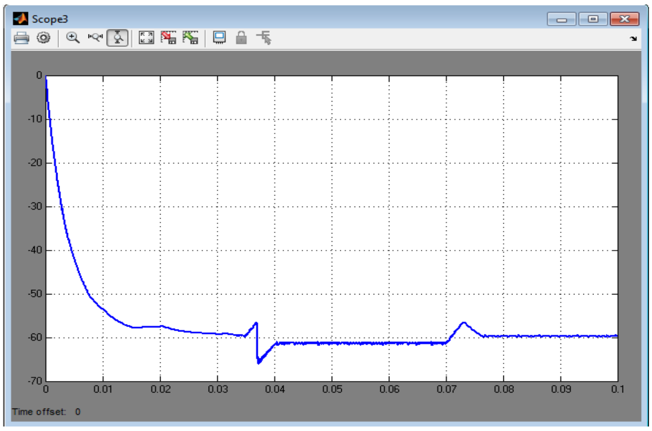

Fig. 5 Line regulation of Negative output Triple –Lift Luo converter: Step change of supply voltage from 10-12.5V at 0.035 sec and 10- 7.5v at 0.07sec

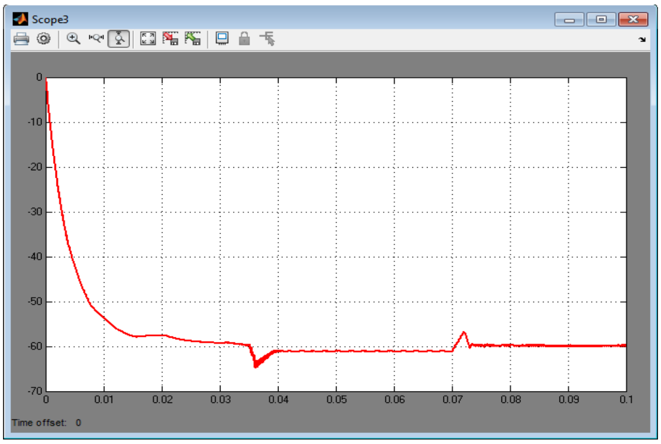

Fig.6 Negative output Triple –Lift Luo converter under load regulation: Step change of resistance from 10-12Ω at 0.035 sec and 10- 8Ω at 0.07sec

V. CONCLUSION

Negative output Triple- Lift Luo converter overcomes the effects of parasitic elements and greatly increases the output voltage of the DC-DC converters. These converters can be used in computer peripheral circuits, medical equipments, and industrial applications, especially for applications with high output voltage. The Triple-lift Luo converter and fuzzy logic controller were built on Matlab environment for load and line regulation. The proposed FLC has satisfactory results for regulating the output voltage.

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